THE REVERSAL OF THE CIRCULATION IN A LIMB.

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I. INTRODUCTION.

THE circulation may be said to be reversed in a limb when the red blood flows through the veins in a direction opposite to the venous normal circulation, and the dark blood returns towards the heart through the arteries.

The reversion may be brought about by cutting the main artery and vein of a limb and uniting the central end of the artery to the peripheral end of the vein and the peripheral end of the artery to the central end of the vein. Then from a functional point of view, the vein becomes an artery, and the artery a vein. The capillary circulation is also reversed.

II. OBJECT.

These experiments have been undertaken with the view, both physiological and surgical, of studying the changes of the circulation of the limb after reversal; and of finding a method of preventing gangrene, when the arteries of a limb become unable to carry the red blood to the capillaries.

III. HISTORY.

The reversal of the circulation in the saphenous vein of a dog was attempted by Dr. Berard, associate professor of surgery in the University of Lyons, and Carrel, in 1902, in the laboratory of A. Lumière. The femoral artery and the saphenous vein having been cut in Scarpa's triangle, the central end of the artery was connected by circular suturing[1] to the peripheral end of the vein. After restoration of the circulation, the saphenous vein appeared greatly distended and pulsating, pulsations being easily perceived even in its course in the leg below the knee. The animal died from infection two days after the operation.

Afterwards, in the laboratory of Professor Soulier, Carrel and Morel succeeded in reversing the circulations in the jugular vein.[2] The carotid artery, and the external jugular vein, having been cut, the central end of the carotid was united to the peripheral end of the jugular, by circular suturing. The jugular became red, distended, and pulsated like an artery. By auscultation, a strong systolic murmur was heard at the anastomosis. The animal was under observation for several months after the operation, and during this time the vein maintained its arterial functions.[3]

Prior to this, in the same year, a Spanish surgeon, San Martin y Satrustegui,[4] attempted to establish a lateral anastomosis between the femoral artery and vein in three goats. Obliteration of the vessels occurred. Afterwards he performed this operation on two patients affected with gangrene of the lower limb. In one case the operation was entirely unsuccessful. In the other, the gangrene stopped, but this was probably due to the fact that the affected portion was amputated at the time the anastomosis was performed.

After these first experiments, a French surgeon, Professor Jaboulay, established a lateral anastomosis of the femoral vein and artery, in a patient suffering from gangrene produced by endarteritis.[5] The operation was not successful, and an amputation became necessary.

In 1903, Gallois and Pinatelle, assistants of Jaboulay, published the results of this operation, and of the experiments which they had made in order to investigate the possibility of the reversal of the circulation.[6] Their experiments were performed on a cadaver. A colored fluid was injected under pressure into the main vein of a limb. The fluid returned immediately by all the other veins of the limb. After occlusion of these veins by forceps, it was impossible to cause the fluid to flow through the main vein. They conclude that the circulation of a fluid through the main vein of a limb, in a direction opposite to the normal circulation, cannot be established, owing to the presence of the valves, and that joining the central end of the artery to the peripheral end of the vein is not justifiable.

In this paper the possibility of the reversal of the circulation, and the nature of the operation necessary to bring it about, will be discussed.

IV. POSSIBILITY OF THE REVERSAL OF THE CIRCULATION.

In order to flow through the veins in a direction reverse to the normal, the red blood must overcome the following three physical obstacles

(*a*) The valves;

(*b*) The numerous anastomosing veins, which decrease the blood pressure by increasing the area of the cross-section of the vessels;

(*c*) The resistance of the capillaries.

Logically, owing to these obstacles the reversal seems impossible. Besides, the experiments of Gallois and Pinatelle indicate that the red blood cannot get beyond competent valves. But their experiments were made on a cadaver. Before adopting their conclusions, therefore, it is necessary to consider that the living tissues have a very strong power of adaptation, and to therefore experiment on the living animal. With this view the two following experiments were performed.

EXPERIMENT I.—Interposition of a segment of the femoral vein between the two cut ends of the femoral artery with reversal of the circulation in two collaterals of the vein (7).

May 12, 1905. Medium-sized, strong young bitch.

A. Technique (summary).—Etherized dog. Four centimetres below Poupart's ligament the femoral artery was sectioned. A displaced segment of the femoral vein was interposed between the two ends of the artery, which restored its continuity. This venous segment had two branches, one of which received the dark blood from the adductors, the other from the quadriceps. (Fig. 1, p. 206.)

After restoration of the circulation, Scarpa's triangle was dissected.

The edges of the wound having been joined by means of several forceps, the skin was covered with hot moist compresses. From time to time the wound was reopened, in order to observe the state of the circulation.

B. Results. On release of the clamps on the vessels, the red circulation was immediately established through the venous segment. But the two small collaterals—the vein of the adductors, and the vein of the quadriceps—remained filled with dark blood.

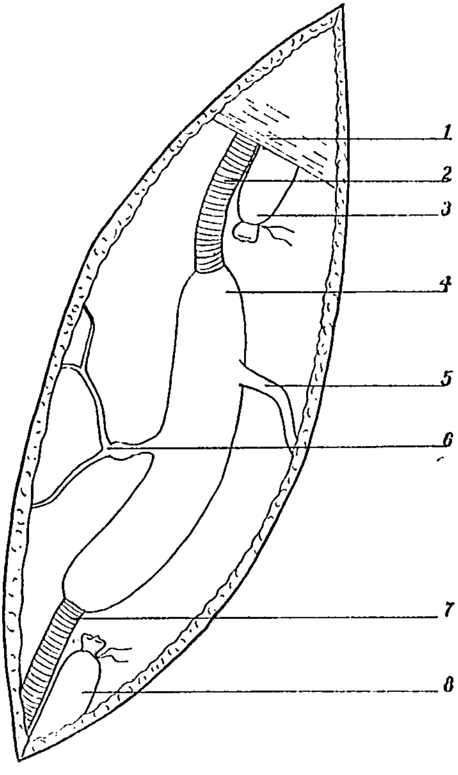

Fig. 1.—Interposition of a segment of the femoral vein, between the cut ends of the emoral artery: 1, Poupart's ligament; 2, femoral artery; 3, femoral vein; 4, a vein from the adductors; 5, a vein from the quadriceps; 6, peripheral end of the femoral artery; 7, peripheral end of the femoral vein.

Fifteen minutes after the operation the red blood had entered the vein of the adductors and pushed the dark blood towards the periphery. A portion of this vein about 3 cm. long and located near the femoral vein assumed an arterial hue and pulsated strongly. The peripheral ramifications near the muscles were yet filled with dark blood. On making a pressure with the hand upon the adductors, in order to increase the blood pressure in the peripheral ramifications of the vein, the dark blood forced all the red blood out of the collateral vein into the venous segment. On release of the pressure upon the muscles, the dark blood was again displaced by the red blood and filled the vein to its peripheral ramifications, the latter remaining dark. The line separating the red from the dark blood was stationary. Therefore, no arterial circulation through the vein of the adductors occurred up to this time.

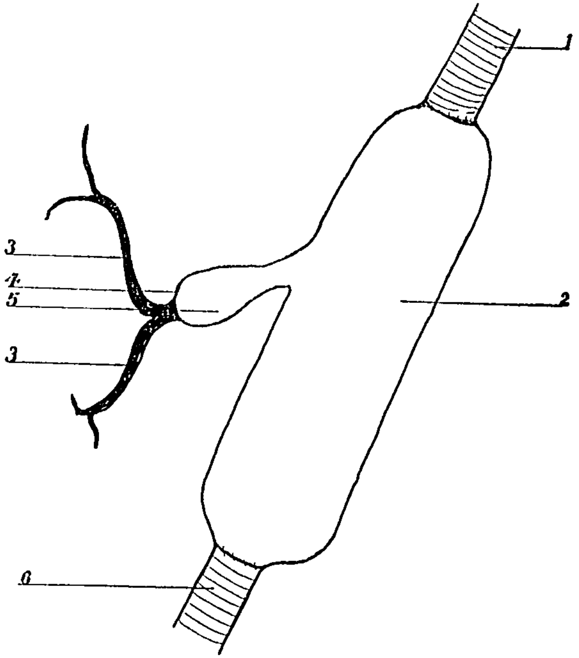

FIG. 2.—Reversal of the circulation through a small valvular vein, one hour after the operation, the valve being not yet forced: 1, central end of the femoral artery; 2, a segment of the femoral vein; 3, small venous branches filled with dark blood; 4, valve; 5, vein filled with red blood; 6, peripheral end of the femoral artery.

The vein of the quadriceps was filled with dark blood. Near its mouth, a small dilatation was observed, above which the blood was red and below which it was dark. (Fig. II.) This dilatation was pulsating like a small aneurysm. Its lower end marked the location of a valve.

When pressure was made upon the muscle the dark blood, passing through the valve, flowed into the red current of the femoral vein. On release of the pressure the red blood penetrated again the dilatated portion but did not pass beyond the valve.

One hour after the operation the adductor vein and its peripheral ramification had become red. The fine branches appeared like small arteries, after having been dissected out from the muscles as far as possible. There was no circulation of red blood through the vein of the quadriceps.

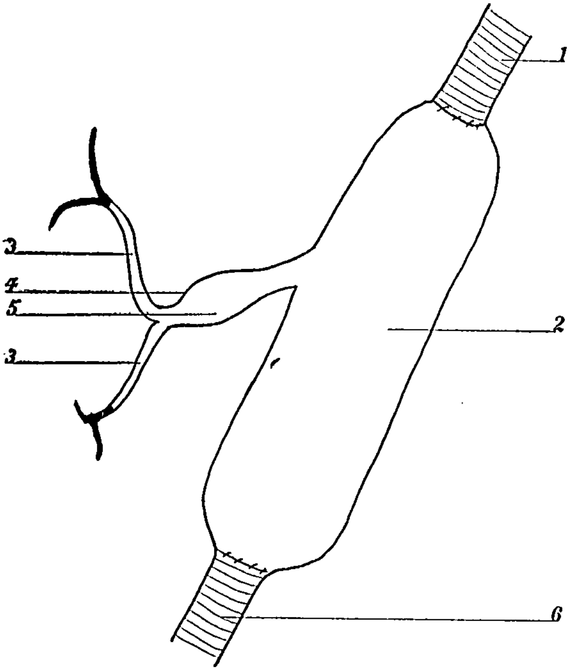

FIG. 3.—Reversal of the circulation through a small valvular vein; two hours after the operation, the valve being forced: 1, central end of the femoral artery; 2, a segment of the femoral vein; 3, small venous branch filled with red blood, the dark blood being compelled to flow towards the periphery; 4, forced valve; 5, vein filled with red blood; 6, peripheral end of the femoral artery.

Two hours after the operation the red blood was seen to pass through the valve of the vein to the quadriceps and to push the dark blood outward, (Fig. III.) but it appeared to stop before reaching the peripheral portion of the vein and the fine intra-muscular branches, which remained filled with dark blood.

Two hours and a half after the operation all the peripheral and intramuscular ramifications had become red. It was not observed if the small artery of the adductors was filled with dark blood at this time.

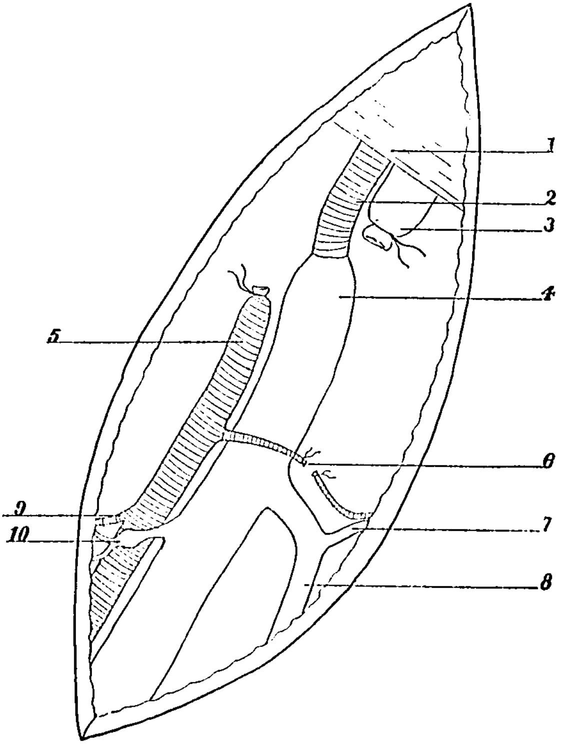

FIG. 4.—End to end anastomosis of the central end of the femoral artery to the peripheral end of the femoral vein: 1, Poupart's ligament; 2, central end of the femoral artery; 3, central end of the femoral vein; 4, peripheral end of the femoral artery; 5, peripheral end of the femoral vein; 6, an artery to the adductors; 7, a vein from the adductors; 8, saphenous vein; 9, an artery to the quadriceps; 10, a vein from the quadriceps.

EXPERIMENT II.—Reversal of the circulation in a limb. June 22, 1905. Medium-sized, very strong young bitch.

A. Technique (summary). Etherized dog. Two centimetres below Poupart's ligament the femoral artery and vein were cut, and the central end of the artery united to the peripheral end of the vein, by circular suturing. (Fig. IV, p. 209.)

After restoration of the circulation, the saphenous vein and its collaterals, the femoral vein, the deep veins of the leg and their collaterals, the superficial veins of the foot, the femoral artery and the small arteries of the adductors and of the triceps, were dissected out. Afterwards the edges of the incision were joined by means of forceps, and hot moist sponges were placed over the part. From time to time the wound was reopened, and the condition of the circulation observed.

B. Results. Immediately after the operation, the arterial blood, passing through the anastomosis, flowed into the femoral vein, which assumed an arterial hue and became very distended. To the touch, strong pulsations were manifest.

The arterial blood did not enter the mouth of the saphenous vein, which was situated in Scarpa's triangle near the apex. The blood in the saphenous vein remained dark. Its walls were distended, owing to stasis of the venous circulation and to the increase of pressure in the femoral vein. No pulsations were perceptible to the touch. Three centimetres below its mouth, a branch was given off to the adductor muscles. This collateral was dark and did not pulsate.

Fifteen minutes after the operation the walls of the femoral vein were less distended. In the popliteal region the vein divided into two branches, one of which was red, the other dark. The saphenous and the superficial veins of the thigh, of the leg, and of the foot were distended with dark blood and did not pulsate.

While inspecting the circulation in the veins, the first valve of the saphenous vein was seen to give way. The red blood slowly entered the mouth of the saphenous vein, pushed the dark blood toward the periphery as far as the mouth of the adductor vein, and then stopped. Immediately below this point a little dilatation filled with red blood was observed. The lower end of this dilatation marked the location of a valve—the second valve of the saphenous vein—below which the vessel was filled with dark blood. Almost immediately the arterial circulation was established through the adductor vein, which became red and began to pulsate.

About thirty minutes after the operation the lower portion of the saphenous vein suddenly became filled with red blood, which flowed towards the upper portion of the vessel; *i.e.*, centrally. Thus, the whole vein became filled with red blood, but the direction of the current was not the same in the superior and the inferior portions of the vessel. By pressing the blood from the superior segment of the vein, and then removing the pressure in order to allow the circulation to become re-established, it was seen that the red blood was flowing from the femoral vein to the vein of the adductors, but that it was unable to get beyond the second valve of the saphenous.

The same experiment showed that, in the portion of the vessel located below the second valve, the blood flowed from the periphery to the centre, *i.e.*, in the direction of the normal venous current. The red blood entered the lower part of the vein through the anastomoses between the deep veins of the leg, but all the valves of the saphenous vein were not yet forced. All the superficial veins were yet dark. On each of them and very close to the saphenous, a small dilatation filled with red blood was observed.

An hour after the operation a small branch from the femoral artery accompanying the vein to the adductor muscles was doubly ligated near its origin and cut between the ligatures. A small opening was then made through the wall, just peripheral to the distal ligature. At first no blood escaped, but about fifteen minutes later, dark blood began to escape, and the rate of flow gradually increased.

The peripheral end of the femoral artery immediately below the ligature was then hemisected. A large hemorrhage of red blood occurred, in which it was possible to see several lines of dark blood, the whole being comparable to the mingling of the water of a small, muddy stream with the clean water of a large one.

Two hours after the operation, dark blood flowed from the branch of the femoral artery to the adductors, on opening the wound in its wall. A transverse section of the peripheral end of the femoral artery gave rise to a large hemorrhage, consisting of red and dark blood in about equal proportions.

Three hours after the operation the saphenous and femoral veins and most of their branches were filled with red blood and pulsated like arteries. Almost all the valves of the saphenous were forced, but when it was emptied by pressure it was observed that the red blood flowed more easily upward than downward, and that the second valve had not been forced.

The artery of the adductors was dark, and had the appearance of a vein. An incision of its wall gave an abundant hemorrhage of dark blood only.

The femoral artery was distended, without pulsations, and of a venous hue. Hemorrhage produced by a lateral wound consisted mainly of dark blood, but in it could be seen a few lines of red blood. All its collaterals were filled with dark blood excepting a deep one coming from the posterior part of the thigh, which remained filled with red blood.

Four hours after the operation, the femoral vein and its collaterals, the saphenous vein, and the veins of the leg and foot, were filled with red blood, but a large collateral in the popliteal region and a few small collaterals along the course of the saphenous vein remained filled with dark blood. If pressure was made on the muscles, the dark blood in the collaterals of the saphenous vein entered the main trunk, where it could be seen through the vessel-wall as a black line in the red blood. This shows that the blood-current through the lower part of the saphenous was directed upward (central), as far as the mouth of the adductor vein, and that, from this point to the femoral vein, the current was downward (peripheral). The second valve of the saphenous had not yet been forced.

Abundant hemorrhage of dark blood from the artery of the adductors was observed on opening the vessel-wall. The femoral artery was distended by dark blood, which was mingled with a very small quantity of red blood which came from an anastomosis with the arteries of the posterior region of the thigh.

The dog was killed five hours after the operation.

These two experiments demonstrate that:

(*a*) The valves prevent, at first, the reversion of the circulation in the veins.

(*b*) After a short time, the valves gradually give way and the red blood flows through the veins as far as the capillaries.

(*c*) Finally it passes through the capillaries, and the arteries are filled with dark blood. Probably dark blood also returns from the capillaries towards the heart through some veins.

(*d*) Practically complete reversal of the circulation is established about three hours after the operation.

V. THE OPERATION PROPER TO ESTABLISH THE REVERSAL.

The above experiments show that the main artery and vein of a limb having been cut, the anastomosis of the central end of the artery to the peripheral end of the vein produces the reversal of the circulation. The operation is completed by uniting the central end of the vein to the peripheral end of the artery, in order to permit the dark blood, which fills the artery when the circulation is reversed, to reach the heart. Perhaps it is not absolutely necessary to perform this second anastomosis, for the dark blood may come back from the capillaries to the heart through other veins. Further observations on this point will be made.

Another operation, consisting of a lateral anastomosis between an artery and vein, without occlusion of the trunk of either vessel, will be discussed, for the reason that it has been used,—unsuccessfully, however,—with a view almost similar to ours.

In order to determine the result of this operation, the following experiment was performed:

Lateral anastomosis of the femoral artery and vein. July 7, 1905. Small-sized, strong young dog.

A. Technique (summary). Etherized dog. A lateral anastomosis was established between the femoral vein and artery in Scarpa's triangle on the right side. Temporary hæmostasis being accomplished by means of suitable artery forceps, a longitudinal incision about 12 mm. long was made through the wall of the artery and vein. The posterior edges and afterwards the anterior edges of the wound, were approximated by a continuous suture. The opening between the artery and the vein was about 1 cm. long.

A short time after the operation the arteries and the veins of the limb were carefully dissected and observed.

B. Results. After removing the clamps on the vessels, the red blood flowed through the anastomosis from the artery to the vein, and the latter became distended. This anastomosis did not produce stenosis of the arterial channel, the circulation through the artery below the anastomosis apparently being normal.

Ten minutes after the operation, above the anastomosis, the vein was red and to the touch, systolic pulsations were manifest. Almost immediately below the anastomosis, the vein became darker, and one and one-half cm. lower it presented the normal hue of a vein. It was markedly distended, but no pulsations were observed. The saphenous vein, in its inferior portion, was distended, but without pulsations.

Sixty minutes after the operation there was a normal red circulation through the artery. An active red circulation through the central end of the vein was observed. No circulation through the peripheral end of the vein could be seen. Below the anastomosis, the first three centimetres of the vein had become red. The walls were distended and pulsating as far as the inferior part of the thigh, but obviously there was no circulation, for the hue remained venous.

The adductor vein, the mouth of which was about two centimetres below the anastomosis, was dark and distended.

No red circulation through the superficial veins of the foot, or through the saphenous vein. Phonendoscopic ausculation showed:

(*a*) On the central end of the artery, a strong continuous murmur, with rude systolic increase;

(*b*) On the central end of the vein, a very strong systolic murmur;

(*c*) On the peripheral end of the artery and of the vein, a continuous murmur.

On clamping the peripheral end of the vein, no modification of the continuous murmur by auscultation on the anastomosis could be detected. When the clamp was placed on the central end, the continuous murmur ceased immediately, and was succeeded by a systolic murmur.

Two hours and forty minutes after the operation, above the anastomosis, and also, as far as 4 cm. below the anastomosis, the vein was red and pulsated strongly, but in the inferior part of the thigh it was dark. The adductor vein was dark, distended and pulsating. Near the mouth a small red column, about 1 cm. long, was observed. The saphenous vein was dark and congested. No red circulation could be detected through the vein of the foot.

A lateral opening made through the wall of the inferior portion of the femoral vein produced a large hemorrhage of dark blood. A complete section of a vein of the foot produced a large hemorrhage entirely of dark blood.

Three hours after the operation no evidence of a reversal of the circulation could be detected. At this point the experiment was discontinued, and the animal killed. The post-mortem examination showed a large communication, about 1 cm. long, between the artery and the vein.

This experiment demonstrates that:

(*a*) After lateral arterio-venous anastomosis a very large portion of the red blood returns immediately toward the heart through the central end of the vein.

(*b*) The peripheral portion of the vein and its collaterals are distended and pulsate, but the valves are not forced and the red blood does not circulate through them.

(*c*) Three hours after the operation, all the valves are yet competent, and no beginning of the reversal of the circulation can be detected.

VI. CONCLUSIONS.

1. The reversal of the circulation in a limb of a dog is possible.
2. It can be established by an end to end arterio-venous anastomosis.
3. Under the same conditions, the lateral anastomosis does not establish the reversal of the circulation.

The permanent results of these operations, a series of which are being performed under aseptic technique in this laboratory, will be published later. If normal nutrition of the limb were possible, and the results of the end to end anastomosis permanent, the operation would perhaps be proposed for the preventive treatment of gangrene following obliteration of the arteries.

We wish to thank Dr. Stewart for granting us the privileges of this laboratory.

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